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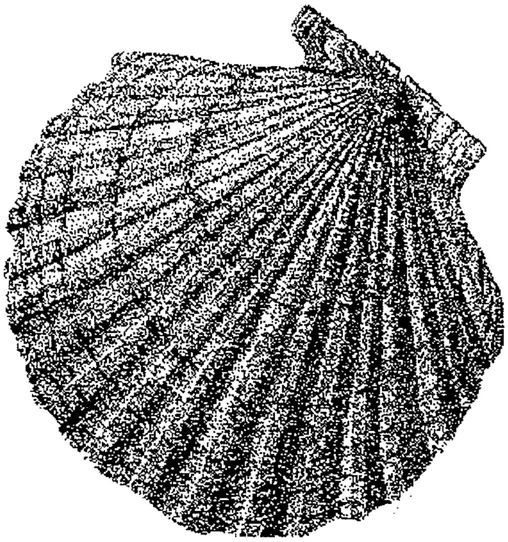
PRELIMINARY EVALUATION OF MULTIPLE DATA SOURCES IN AN AGE-STRUCTURED MODEL FOR WEATHERVANE SCALLOPS IN KAMISHAK BAY, ALASKA

by

William R. Bechtol



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ABSTRACT

The weathervane scallop *Patinopectin caurinus,* a bivalve that exhibits aggregated distributions and longevity in excess of 20 years, has been commercially fished in Kamishak Bay, Alaska, since 1983. A variety of data from the commercial fishery and from Alaska Department of Fish and Game (ADF&G) surveys were evaluated for utility in an age-structured model for this population. Commercial fishery data included annual harvest, effort, and age composition; ADF&G survey data in 1984 and 1996 included estimates of scallop abundance, biomass, age composition, and weight at age.

The age-structured model estimated an abundance of 10.4 million weathervane scallops in Kamishak Bay in 1997. This model applied equal weighting of all three data sources: fishery age composition, survey age composition, and survey biomass. The corresponding ages of 50% selectivity of 4.3 years for the fishery and 0.3 years for the ADF&G survey seemed reasonable because a small-mesh liner is used in the survey gear but not in the fishing gear. The model estimate of an instantaneous natural mortality rate of 0.14, corresponding to an annual mortality rate of 13%, was consistent with published natural mortality estimates. Model results indicated that commercial fishery harvest rates in the 1990s ranged from 2.6% of the standing stock in 1994 to a peak of 4.7% in 1996. The model was sensitive to starting values for many parameters, particularly for survey selectivity. Model results indicated that some inconsistencies existed between the survey age and fishery age data sets and also a vulnerability to biased survey biomass estimation. The latter was indicated by the response to what was likely a substantial underestimation of the true population by the 1984 survey. These model shortcomings may be due to the lack of a more extensive time series of surveys, an issue to be resolved by conducting surveys more frequently in the future.

INTRODUCTION

The weathervane scallop *Patinopectin caurinus* is a bivalve that exhibits aggregated distributions and longevity in excess of 20 years (Kaiser 1986). The "meat", or abductor muscle, of this species is highly desirable for human consumption. The weathervane scallop resources are co-managed by the Alaska Department of Fish and Game (ADF&G) and the National Marine Fisheries Service (NMFS) off the coast of Alaska (Shirley and Kruse 1995; North Pacific Fishery Management Council 1997). Co-management evolved because scallop fisheries have primarily occurred in waters of federal jurisdiction located 3-200 nautical miles from shore, but shellfish fisheries off the coast of Alaska have historically been managed with an area management program implemented by the State of Alaska. Federal fisheries are currently under a license moratorium, potentially becoming a license limitation program in the future.

One weathervane scallop fishery occurs in the Kamishak Bay District in the southern portion of Cook Inlet, Alaska (Figure 1; Table 1). This fishery has only occurred since 1983 and has been characterized by small mean vessel size and small harvests relative to other weathervane scallop fisheries in Alaska (Shirley and Kruse 1995). During fishery development, management strategies were adopted that included limits on the bycatch of king and Tanner crabs, and requirements for observer coverage and logbooks (Kimker 1996). Gear was also restricted to a single 1.8 m (6 foot) wide dredge with a minimum ring size of 102 mm (4 inch). Harvests were computed as the weight of meats retained by the fishery with annual harvest guidelines established as a constant catch strategy of 9.0 metric tons (20,000 lb) of meats except for 1996 when the guideline was increased to 12.7 metric tons (28,000 lb) based on the results of a 1996 summer survey and the lack of a fishery in 1995. Regulations allowed an open season of 15 August through 31 October, although the fishery has rarely lasted more than three weeks in recent years. Annual participation is usually less than five vessels. Fishery managers have expressed concern about the appropriateness of the current harvest strategy and how the scallop population has changed over time under previous harvest and environmental patterns. The goals of this study were: (1) to develop an age-structured model to describe the characteristics of the Kamishak Bay weathervane scallop population, particularly trends in annual abundance and estimates of natural mortality; and (2) to evaluate the available survey and fishery data for utility in the model.

MATERIALS AND METHODS

Study Area

Although weathervane scallops are found throughout the Kamishak Bay District, the majority of the fished population is aggregated in a limited area or bed located east of Augustine Island (Figure

2). This study, as well as previous surveys, focused on this aggregation (Hammarstrom and Merritt 1985; Bechtol and Gustafson *under review*). The scallop bed occurs on a flat or gradually-sloping bottom ranging from 30-90 m (20-50 fathoms) in depth with muddy or sand substrate interspersed with shale outcroppings.

Data Sources

Several types of fishery and survey data were considered for the model. Fishery harvest and catch-per-unit-of-effort (CPUE) data were available from the 1983-1987, 1993-1994, and 1996 seasons (Table 1). Harvests were derived from ADF&G fish ticket landing reports. CPUE data were obtained from vessel logbooks and ADF&G observer data. The use of CPUE data as a model input was rejected because of problems with effort standardization due to time series increases in gear efficiency and mean vessel size. Because the fishing fleet usually numbers fewer than five vessels, changes to an individual vessel can drastically alter mean fleet performance. Age composition data were also available for all fishing years except 1983 and 1984 (Figure 3). To estimate the 1984 fishery age composition, I first calculated relative selectivity of the 1996 fishery compared to the 1996 survey. I then adjusted the 1984 survey composition by the selectivity factor to estimate the 1984 fishery composition. After applying mean scallop weight-at-age to the estimated age composition, I calculated the expansion factor needed to produce the observed 1984 harvest biomass. Data from 1983 were excluded from the model because no age data were available. Scallops were aged in the Homer ADF&G office with subsamples re-aged for validation in the Kodiak ADF&G office. For time periods when sequential years of data were available, the annual progression of strong year classes was evident.

Survey data included population abundance and biomass estimates from area-swept expansions of the catch from ADF&G surveys in 1984 and 1996 (Hammarstrom and Merritt 1985; Tables 1 and 2). In both surveys, dredge catchability was assumed equal to 1.0 when expanding area-swept estimates. Survey age compositions were obtained from both surveys; mean scallop weight-at-age was obtained from survey samples in 1996. Both surveys used a 2.4 m (8 foot) wide dredge modified by a 38 mm (1.5 inch) mesh liner to aid the retention of juvenile scallops. The Kamishak Bay scallop bed was delineated into a grid of potential sample stations, each measuring 3.4 km^2 (1.0 square nautical miles; Figure 2). The 1984 survey used a 2-stage, systematic design with greater sample station densities in areas of higher fishery catches. The 1996 survey used a systematic design to sample alternate stations. Within each survey station, the survey dredge was towed for 1.9 km (1.0 nautical mile). Poor weather constrained sampling efforts along the northern portion of the scallop bed in the 1984 survey and along the southern portion in the 1996 survey.

Age-Structured Model

Hilborn and Walters (1992) and Megrey (1989) reviewed age-structured models that incorporate heterogeneous data. The age-structured model for scallops in Kamishak Bay incorporated auxiliary information, similar to models developed by Deriso et al. (1985). In my conceptual model of the annual cycle of events affecting the weathervane scallops in Kamishak Bay (Figure 4), ages increment in late December to coincide with the approximate time of annulus formation (Hennick 1970). Although scallops observed from Kamishak Bay ranged from age 0 to age 24, the population model only accounted for scallop ages 1-16 that were observed in the fishery in most years. The model introduced age-1 scallops as recruits into the summer population. Fishing mortality was deducted through the summer fishery, then the remaining population was subjected to winter mortality before being incremented to the subsequent summer population. Because scallop shell height was measured on samples collected from the fishery and surveys in the summer, size-at-age was determined from summer samples. Age-1 recruitment in 1996 was calculated as the median of age-1 scallops estimated for the 1984-1995 population years. Through the use of fishery and survey selectivity curves, the model accommodates differences among the age compositions of the underlying population, the field surveys, and the commercial fisheries.

My model incorporated the following assumptions:

1. Commercial fishery selectivity and survey selectivity are age-specific and can be described by independent logistic functions whose shapes are determined by model-estimated parameters.
2. Catchability of fully-selected ages equals 1.0.
3. Age classes from age 1-16+ are all present in the estimated population; cohorts older than age 16 are a minor component of the population and adequately represented by a single class, age 16+.
4. Instantaneous natural mortality is constant among years and cohorts.
5. Measurement errors in each of the data sources are independent.
6. The model is correctly specified with respect to the available data such that parameter estimates are not correlated and differences between model estimates and observed values result from measurement error, not errors in mathematical description of the underlying processes.
7. A nonlinear least squares approach that minimizes weighted residual sums of squares provides the best estimate of the true parameter values when age compositions are arc sine transformed.

Assumptions 1 and 2 control the curvature in relationships among model values. Assumptions 3-5 are required for assumption 6 to hold. Assumption 7 is the basis for the model. This age structured model fits a variety of data measured in different units and of varying utility in identifying true parameter values. Unlike least squares linear regression, there is no rigid statistical theory underlying the parameter estimation procedure in the model. The rationale for assumption 6 is that the best estimates of the model parameters should provide a reasonable fit to all available data. Some data were transformed to achieve symmetric and approximately normal error distributions, although the robustness of the parameter estimates to departures from normality is unknown (Funk 1994).

Model parameters are shown in Appendix A. The model tunes to both fishery and survey data (Figure 5). Initial parameter inputs for annual survival and age-1 recruit abundance are model-adjusted to accommodate available fishery and survey data. Cohort survival is described by a reduction equation. Thus, after deduction of the fall commercial catch and application of an overwinter survival rate, cohort abundance is updated each summer.

Observed fishery parameters included an 8.5% meat recovery (unpublished data), harvest biomass, mean whole scallop weight-at-age, and age composition. Cohort abundance in each year's commercial fishery was determined from observed fishery age composition, observed harvest biomass, and mean scallop weight-at-age. Some scallops ages are partially selected by the fishery due to regulations that specify a minimum ring size in the dredge bag (Kimker 1996). For each year, expected commercial fishery age composition was calculated from an age-specific selectivity function and estimated population cohort abundance. Fishery selectivity, described by a logistic function, was assumed to be constant over the range of years examined by the model. Model fit to the fishery age data was calculated as a sums-of-squares (SSQ) difference between expected and observed fishery age compositions. To stabilize the variance prior to SSQ calculations, observed and expected fishery age compositions were transformed by taking the arc sine of the square root of the composition proportion (Funk 1984). Thus, fishery age composition was fit across ages 1 to 16+ and years 1984 to 1987, 1993, 1994, and 1996.

For tuning the age model to survey data, observed parameters included survey biomass, abundance, and age composition from the 1984 and 1996 surveys (Hammarstrom and Merritt 1985; Bechtol and Gustafson *under review*). The age model also calculated a survey selectivity curve to estimate the proportion of each age class available to the Kamishak Bay survey. Similar to fishery selectivity, survey selectivity was expected to be asymptotic with age, and a logistic function was used and assumed to be constant over the range of years examined by the model. Model fit to the survey age data was calculated as a SSQ difference between expected and observed survey age compositions. Observed and expected survey age compositions were also transformed by taking the arc sine of the square root of the composition proportion. Survey age composition was fit across ages 1 to 16+ and for years 1984 and 1996.

Survey biomass estimates from 1984 and 1996 were also compared to expected survey biomass using SSQ differences. Expected survey biomass was obtained as the products of cohort abundance, mean weight-at-age, and survey selectivity-at-age. Expected and observed biomass estimates were log transformed because a lognormal error structure is commonly found for abundance data (Funk et al. 1992).

Finally, a total SSQ was computed by adding the SSQ for each of the components: fishery age composition, survey age composition, and survey biomass. A nonlinear optimization function within Microsoft Excel Solver[1] was used to estimate parameter values that minimized the total weighted SSQ from the heterogeneous auxiliary data. The solver obtained estimates of the variables in each one-dimensional search using linear extrapolation from a tangent vector, central differencing for estimates of partial derivatives, and a quasi-Newton method for computing the search direction. The precision level was set at 0.00001. Cohort abundance was constrained to be greater than or equal to zero in all years because negative population values were unrealistic.

[1] Vendor and product names are provided to document methods and do not represent an endorsement by ADF&G.

Multiplicative weighting factors, or λ's, were assigned to each sum of squares component. Theoretically, each SSQ component should be scaled to a similar order of magnitude, so that each contributes similarly to the total SSQ when λ's were equal. However, the quantity of data from each data source varied widely: 96 fishery age composition data points, 32 survey age composition data points, and 2 survey biomass data points. Therefore, model robustness, and the utility of the different data sources in the model, was examined through model scenarios that varied the emphasis, or weighting, on the available data sources in different model runs. In these evaluations, the weighting of an individual SSQ was varied from 0.1 to 100 while all other SSQ weights were held constant at 1.0. Some model runs were rejected because they yielded unrealistic results, such as selectivity curves that placed the age of 50% selectivity at negative values or greater than age 20.

The ASA model estimated a total of 32 parameters: 27 initial cohort sizes, two fishery selectivity function parameters (α and β), and two survey selectivity function parameters (φ and τ), and the survival rate parameter (S). The model's SSQ equations referred to 130 data observations with 98 degrees of freedom and a data to parameter ratio of approximately 4:1. However, the information available from the data was less than if all observations were independent.

RESULTS

Model runs with data source weightings of 0.1 to 100 generally yielded results deemed acceptable based on an arbitrary determination of realistic values for model estimates of population abundance, the ages of 50% selectivity in the fishery and the survey, and annual mortality. Runs weighting the fishery data at 5.0 or 100.0 were rejected because they produced negative instantaneous mortality estimates.

Greater emphasis of the fishery age composition data increased model fit (i.e., decreased SSQ's) to fishery age data but decreased fit to survey age data (Figure 6). Greater emphasis, or weighting, of the survey age composition data increased model fit to the survey age data and decreased the fit to the fishery age data. The model fit to survey biomass data showed little response to increased weighting of either the fishery age or the survey age data except for a decrease in fit at emphasis levels greater than 1.5. Similarly, greater weighting of the survey biomass data increased the model fit to the survey biomass data but generated little change in model fit to the survey age and fishery age data sets.

Throughout the range of weighting scenarios, the resultant ages of 50% selectivity ranged from 4.3 to 4.5 for the fishery and from 0.0 to 4.0 for the survey. Both of these survey values represent artificial bounds placed upon the model estimates to prevent unrealistic results. At values of unity, or equal weighting of 1.0 for all data sources, the ages of 50% selectivity were 4.3 years for the fishery and 0.3 years for the survey. As the weight applied to the fishery age composition data was increased from 0.5 to 5.0 years, the model estimated ages of 50% selectivity generally declined (Figure 7). The fishery age only declined from 4.5 to 4.3 years whereas the age in the survey declined more dramatically from 1.4 to 0.0 years; some anomalies were indicated by an increase to 0.1 years in survey age at weighting of 2.0 for the fishery data. As the weighting of the survey age data was increased from 0.1 to 100.0, the ages of 50% selectivity for both the fishery and the survey decreased then increased. The age in the fishery declined from 4.4 to 4.3 years before increasing to 4.5 years. The age in the survey again showed a more dramatic change by decreasing from 4.0 years for weighting of 0.1 to an age of 0.0 years for weighting of 0.25, then increasing to 2.0 years for weighting of 100. Increasing the emphasis applied to the survey biomass data produced virtually no change in the ages of 50% selectivity as the fishery age remained stable at 4.3 years and survey age decreased only slightly from 0.4 to 0.3 years.

Model runs produced estimates of instantaneous natural mortality (M) ranging from 0.14-0.27 among the different weighting scenarios (Table 3). With equal weighting values of 1.0 applied to all data sources, M was estimated to be 0.14, corresponding to an annual mortality rate of 13%. Under the more extreme scenarios with weighting values <0.5 or >1.5, estimates of M tended to increase. For example, M was estimated to equal 0.17 for weighting of 0.1 for the survey age data and 0.15 for weighting of 5.0. Similarly, weighting the survey age data at 0.1 yielded M=0.23 and weighting of 100.0 yielded M=0.27. In contrast, the increase in weighting of survey biomass data from 0.1 to 100.0 caused mortality estimates to decline from 0.15 to 0.14.

Model estimates of the annual recruitment of age-1 scallops ranged from 600 scallops to 29.7 million scallops (Figure 8). At values of unity, a weighting of 1.0, for all data sources, the abundance of age-1 recruits ranged from 0.8 million scallops in 1983 and 1991 to 3.1 million scallops in 1993. Similar time series trends were depicted for all data weighting scenarios. In general, periods of greatest recruitment were indicated for the mid-1980s with peak recruitment around 1986, and for years around 1993. Low recruitment years were indicated for 1984, 1991, and 1995. For both survey age and fishery age composition data, outliers in the recruitment schedules resulted from extreme weighting options that were either <0.50 or >5.00. In contrast, different weightings of survey biomass data yielded little change in model-estimated recruitment schedules. The largest recruitment outliers occurred for extreme weighting of the survey age composition data.

The age model indicated that the abundance of the weathervane scallop population generally increased over the time series (Figure 9). Estimates of the annual population among all years and weighting scenarios ranged from 20,000 to 52.0 million scallops. Outlier estimates were most prevalent from data source weighting >0.1 or <5.0. At values of unity, or a weighting of 1.0 for all data, the estimated population generally increased from 4.9 million scallops in 1983 to a peak of 11.4 million scallops in 1993 and 1994, then declined to 10.4 million in 1997. Most model runs indicated a high population abundance in 1988 followed by a slight decline before increasing to the 1994-1994 peak. All model runs with data weightings of 0.5 to 2.0 yielded 1997 population abundance estimates in the range of 10.4 to 11.0 million scallops.

DISCUSSION

Based on the available data and subject to the placement of bounds on some parameters estimated by the age structured model, a population abundance of 10.4 million scallops in 1997 appeared to be a reasonable estimate for the weathervane scallops of Kamishak Bay, Alaska (Figure 9). This estimate makes full use of all three data sources, fishery age composition, survey age composition, and survey biomass, and applies equal weighting to all three data sources. A younger age of 50% selectivity was expected in the survey because of the use of a small-mesh liner in the survey gear. Thus, the ages of 50% selectivity of 4.3 years for the fishery and 0.3 years for the ADF&G survey that corresponded to equal weighting of all three data sources also seemed reasonable (Figure 7). Commercial scallop dredges also select against the young scallops that were abundant in some stations during the survey (Table 2).

The instantaneous natural mortality rate of 14% estimated by the model is reasonable given potential weathervane scallop longevity in excess of 20 years (Table 3). Kruse (1994), using several methods for weathervane scallops off Alaska, estimated M ranged from 0.04-0.25 (annual mortality of 4-22%), with a median estimate of 15%. Application of the empirical method by Hoenig (1983) with the maximum observed age of 24 years yielded M=0.17 (16% annual natural mortality rate) for Kamishak Bay weathervane scallops. Based on population abundance estimates from model runs with equal weighting of all data sources, commercial fishery harvest rates in recent years ranged from 2.6% in 1994 to 4.7% in 1996. Annual harvest rates for long-lived species must be conservative to maintain sustainability (Leaman and Beamish 1984). As a biological reference point, the natural mortality rate is often treated as an upper bound for fishing mortality (Alverson and Pereya 1969). Under this approach, existing harvest policies appear to be conservative and should prove sustainable under the current environmental conditions. However, annual recruitment and abundance will need to be monitored closely as the fishery becomes a more consistent factor in annual population productivity (Figure 2).

An additional data source that remains to be explored is bottom trawl survey data. The Kamishak Bay District has been surveyed with bottom trawl gear annually since 1991 as part of an assessment for king and Tanner crabs. Preliminary observations indicate that the trawl survey gear appears to have a low selectivity for scallops younger than age 4. Although the trawl survey data may not be an appropriate indicator of scallop recruitment, this data may prove useful as a supplemental index with which to further clarify long-term trends in overall scallop population abundance.

The age model was sensitive to starting values for many parameters, particularly the survey selectivity parameters. Over a variety of unrestricted weighting scenarios and parameter starting values, ages of 50% survey selectivity that were <0.0 or >20.0 years and population estimates in the billions of scallops were not uncommon. The placement of bounds on some model parameters improved the success of achieving realistic solutions from model run efforts. Differences in model fit between survey age and fishery age compositions indicated some inconsistencies existed between these data sets (Figure 6). In particular, increased weighting of survey data decreased model fit to age data, and visa versa. A lack of a more extensive time series may have limited the utility of the survey data and likely contributed to these inconsistencies. Additional years of survey samples should facilitate better tracking of cohort strengths. In contrast, model runs showed little response to changing emphasis of survey biomass estimates (Figure 9). The survey "time series" was represented by only two, widely separated, data points, 1984 and 1996. There was relatively little cost, in terms of reduced fit to other data sources, for the age model to fully accommodate both the 1984 and 1996 survey biomass estimates. Essentially, the model is creating a time-series biomass between two points in time. In addition, observations of the scallop bed distribution in the 1996 survey indicate that the 1984 survey may have substantially underestimated the true population if a similar geographic distribution existed in 1984 (Figure 2). Similarly, catchability, which was assumed to equal 1.0 during both the 1984 and 1996 surveys, can substantially affect the population estimate. Video recordings indicate weathervane scallops are sedentary when approached by a scallop dredge (personal observation). Therefore, an assumption of 1.0 is likely a maximum catchability value, which implies that area-swept estimates are minimum values. Vulnerability to incomplete biomass estimation is a model shortcoming that has previously been identified in other applications (Bechtol and Brannian 1996; Bechtol and Gustafson *under review*; Otis et al. 1998). Anticipated increases in survey frequency in the future, coupled with further catchability studies, will likely resolve some of the problems associated with survey data. However, this model shows substantial utility in merging available data sets to develop a better understanding of population dynamics of weathervane scallops in Kamishak Bay.

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Table 1. Fishery data and survey estimates for weathervane scallops in Kamishak Bay, Alaska, 1983-1996.

Year[a]	Fishery Catches: Harvested Meats (mt)	Fishery Catches: CPUE (kg/hr)	Survey Whole Weight (kg)
1983	1.1	9.8	
1984	2.9	11.5	940,000
1985	5.4	17.9	
1986	7.0	16.4	
1987	0.2	6.8	
1988	No Effort		
1989	No Effort		
1990	No Effort		
1991	No Effort		
1992	No Effort		
1993	9.1	17.3	
1994	9.3	20.2	
1995	Closed		
1996	12.8	24.0	2,485,000
1997	9.2	23.1	

[a] Fishery data from 1983 was not included in the model.

Table 2. Weathervane scallop age composition for 1984 and 1996 surveys and 1984-1996 fisheries.

Age	Mean Weight	Scallop Age Composition (sample abundance)														
		Survey		Commercial Harvest												
(years)	(g)	1984	1996	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
1	12.7	256	187	7									3			2
2	69.2	302	72	108									18			11
3	146.5	787	101	377		8							28	26		196
4	217.7	91	256	55	20	39	2						51	16		148
5	272.9	3	154	108	53	90	35						91	40		146
6	311.9	13	66	39	25	83	29						162	32		43
7	338.1	82	78	69	11	9	33						156	60		65
8	355.1	65	134	4	24	3	9						99	80		41
9	381.1	18	92	24	11	11	11						46	103		56
10	408.8	41	92	41	11	14	17						24	96		83
11	430.9	52	81	42	20	18	12						15	58		76
12	448.4	99	83	39	13	12	13						12	38		67
13	462.1	86	57	29	6	4	4						8	18		31
14	472.8	58	27	33	1	4	2						6	15		17
15	481.1	18	9	21	2		1						5	8		4
16+	487.5	18	23	3									3	23		18
Total		1,989	1,512	999	197	295	168	0	0	0	0	0	727	613	0	1,004

Table 3. Changes in instantaneous mortality rate in response to variations in weighting of individual data sets.

	Weighted Data Source[a]		
	Fishery Age Composition	Survey Age Composition	Survey Biomass
Data Source Weighting	Model-Estimated Instantaneous Mortality Rate		
0.10	0.165	0.226	0.147
0.25	0.152	0.162	0.143
0.50	0.144	0.142	0.141
0.75	0.142	0.140	0.141
1.00	0.140	0.140	0.140
1.50	0.139	0.144	0.140
2.00	0.139	0.148	0.140
5.00	0.146	0.171	0.140
10.00	-	0.195	0.140
100.00	-	0.270	0.139

a - Model simulation made with other data sets weighted at unity except for weighting of indicated data source.

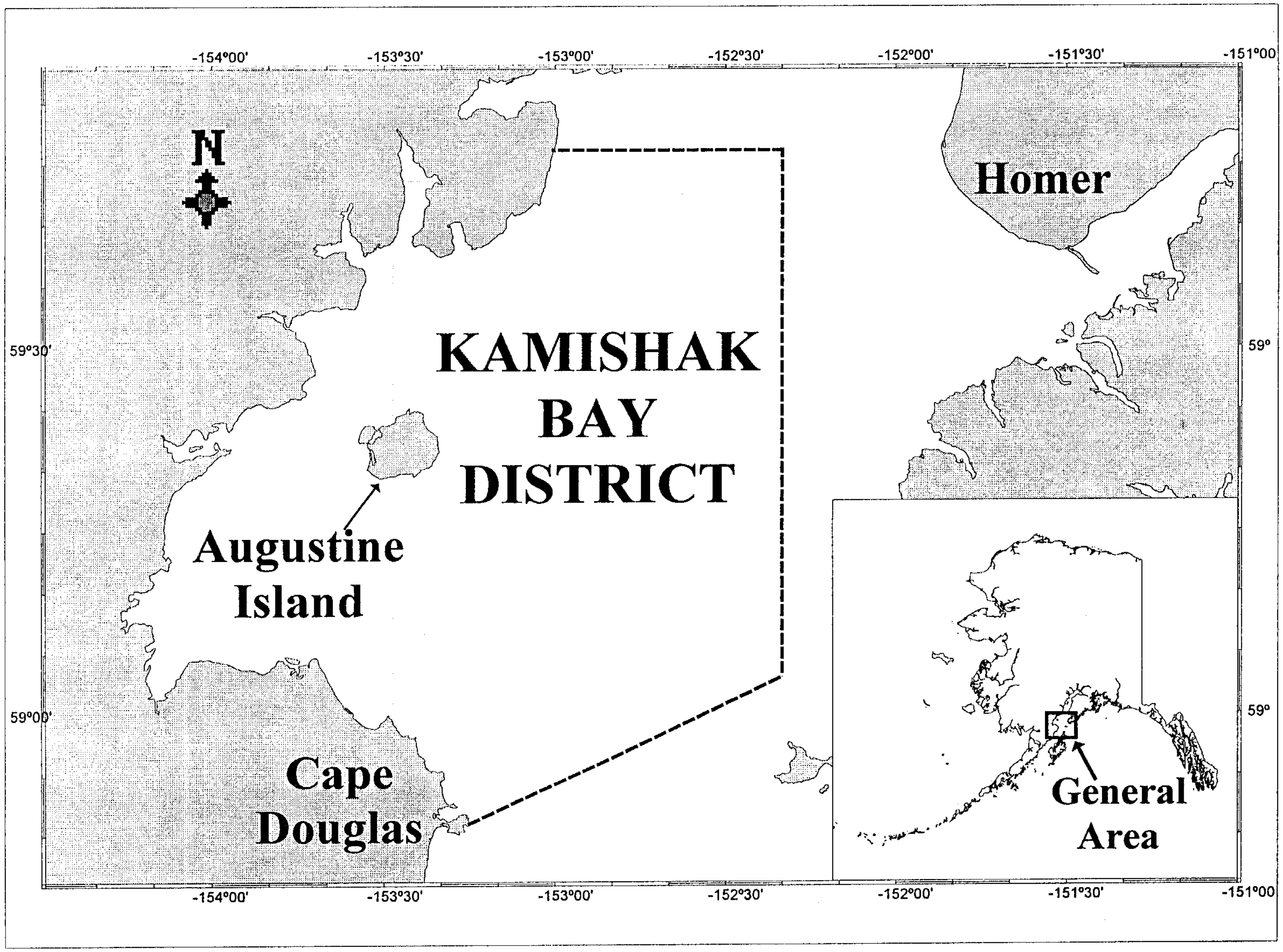

Figure 1. Kamishak Bay District in the Cook Inlet Management Area.

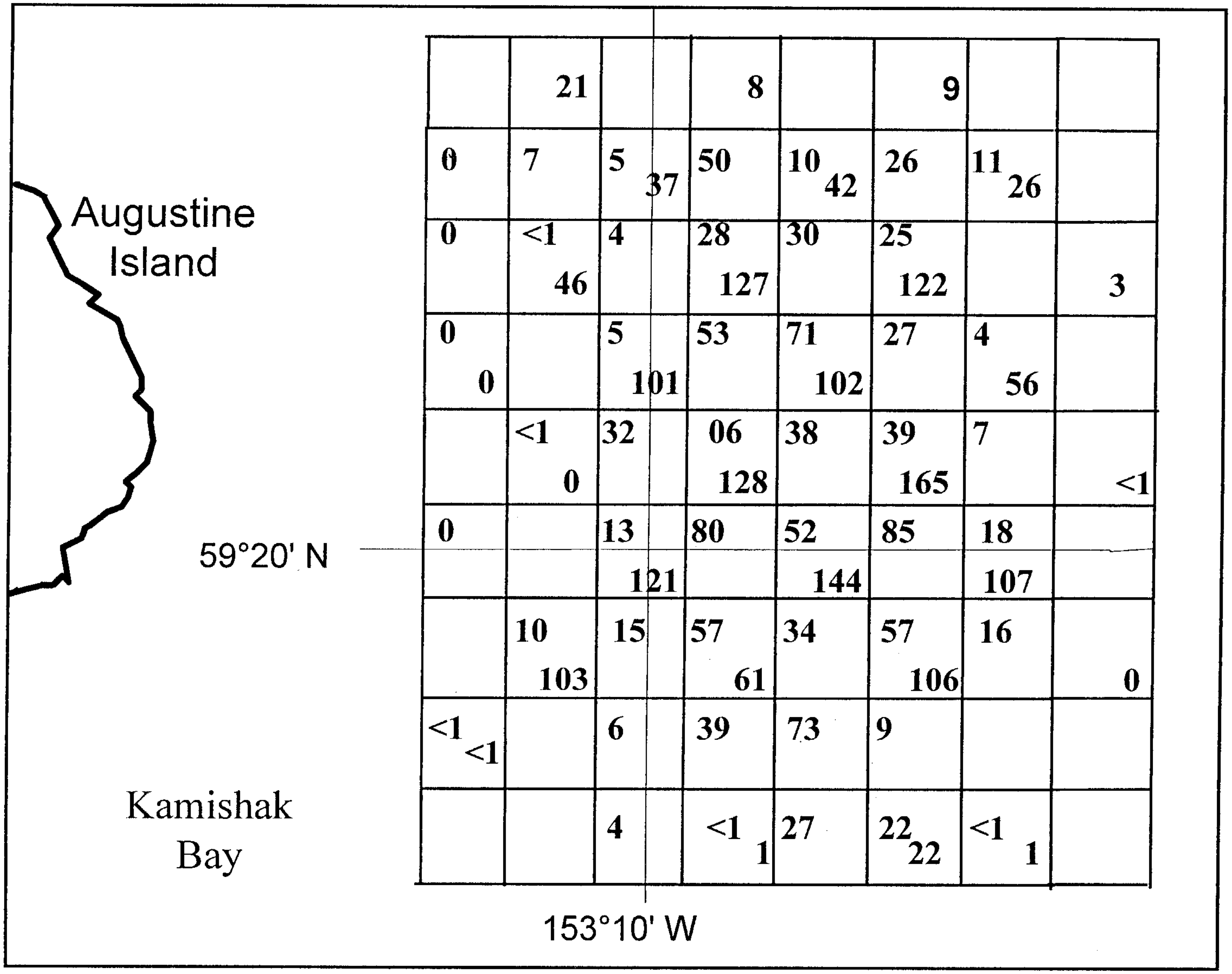

Figure 2. Catch rates (kg per 1.0 nm tow) of weathervane scallops showing aggregation during dredge surveys in 1984 (upper left numbers) and 1996 (lower right numbers) of Kamishak Bay, Alaska.

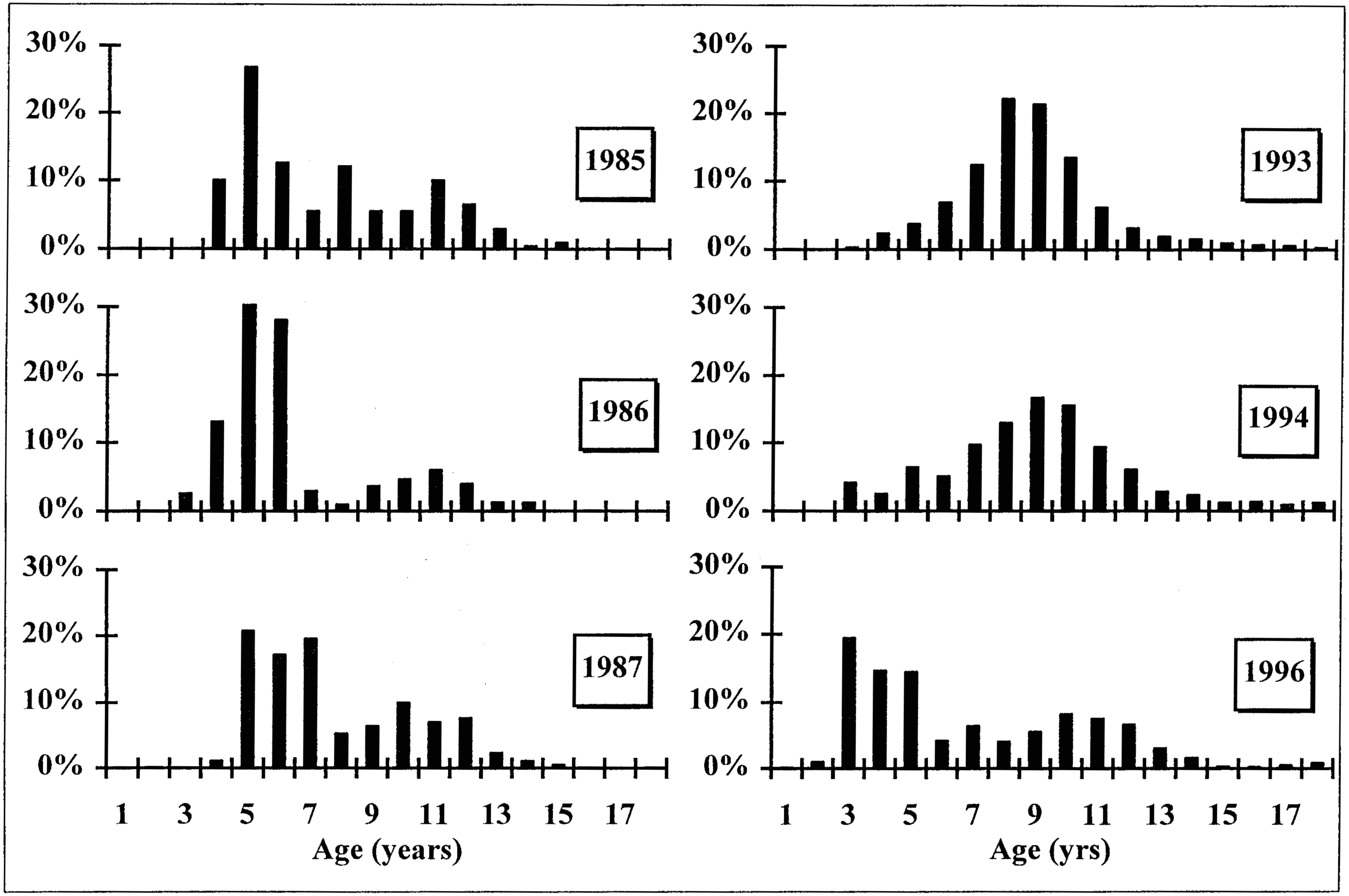

Figure 3. Age composition from the commercial fishery for weathervane scallops in Kamishak Bay, Alaska.

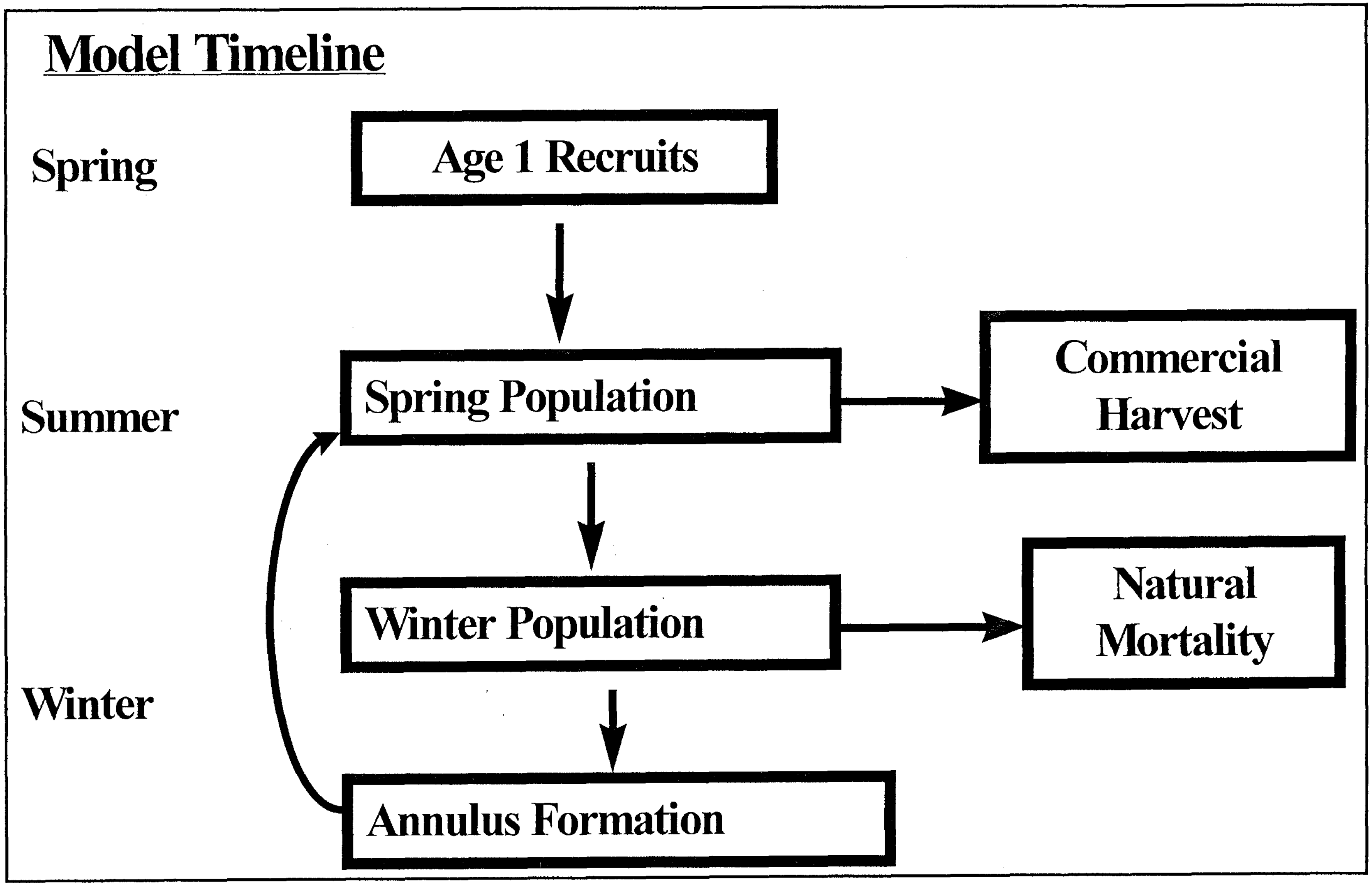

Figure 4. Conceptual timeline of growth and survival in an age model for weathervane scallops in Kamishak Bay, Alaska.

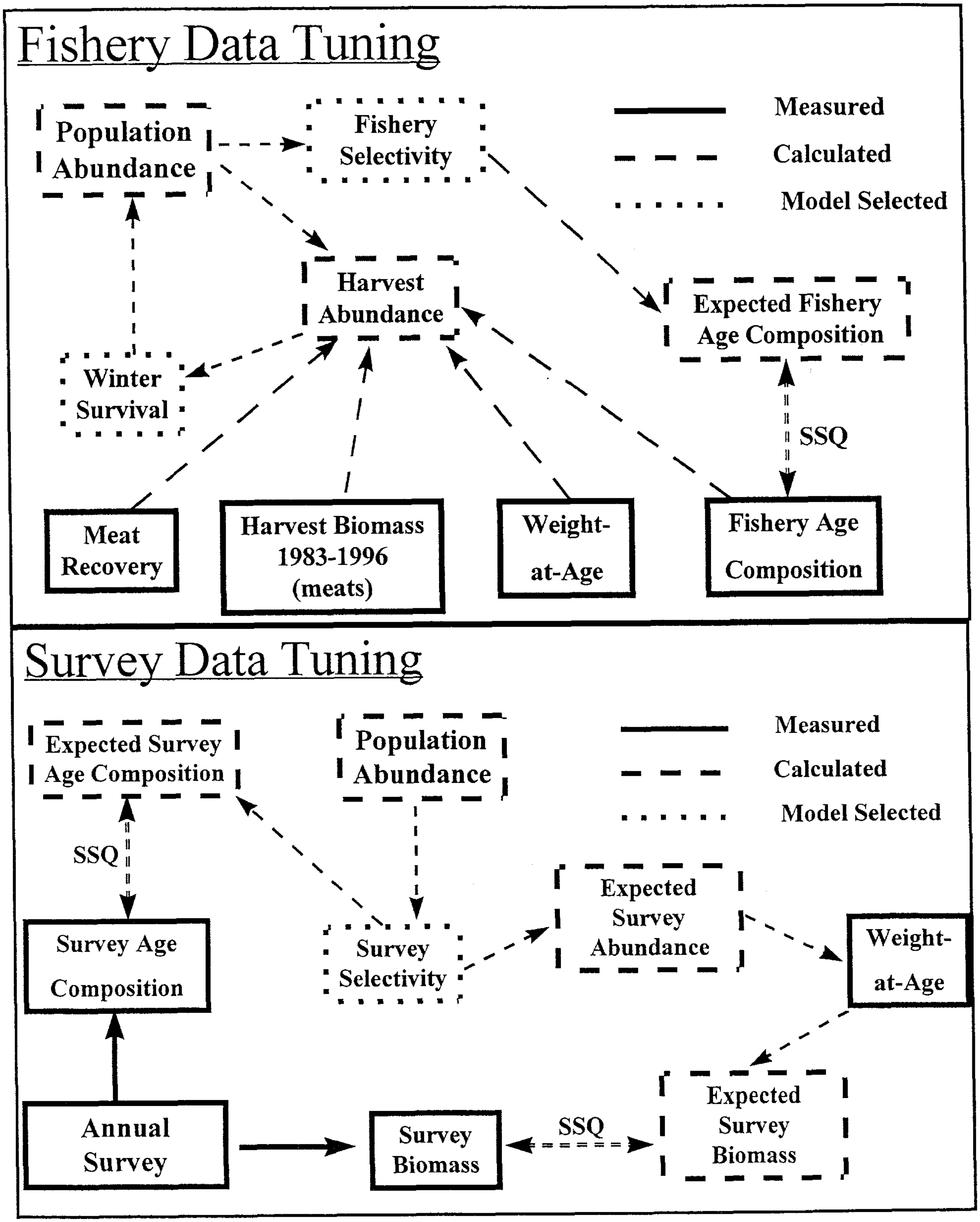

Figure 5. Components involved in model tuning model to fishery and survey data.

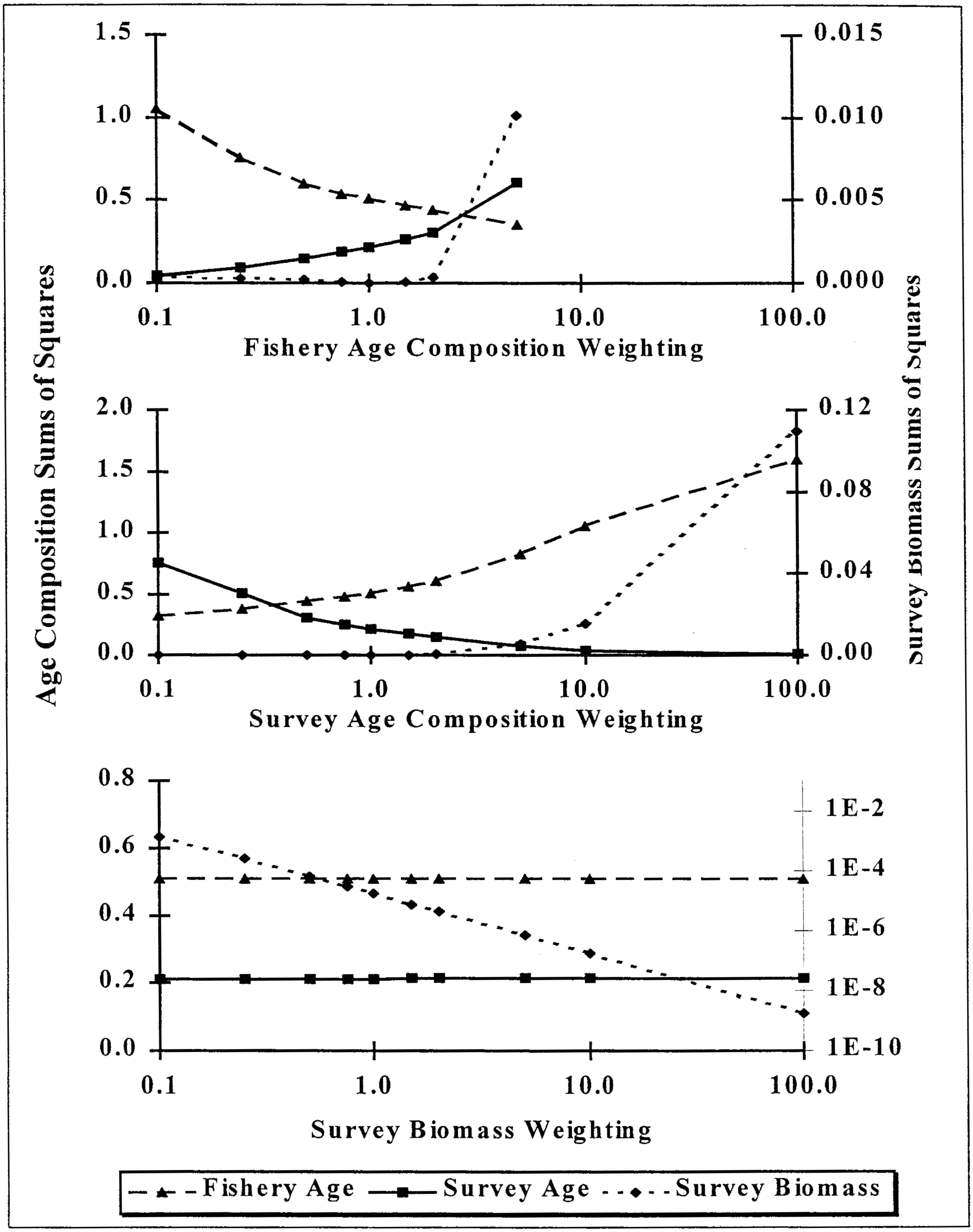

Figure 6. Changes in the residual sums of squares in response to variable weighting of survey age and fishery age composition data and survey biomass data.

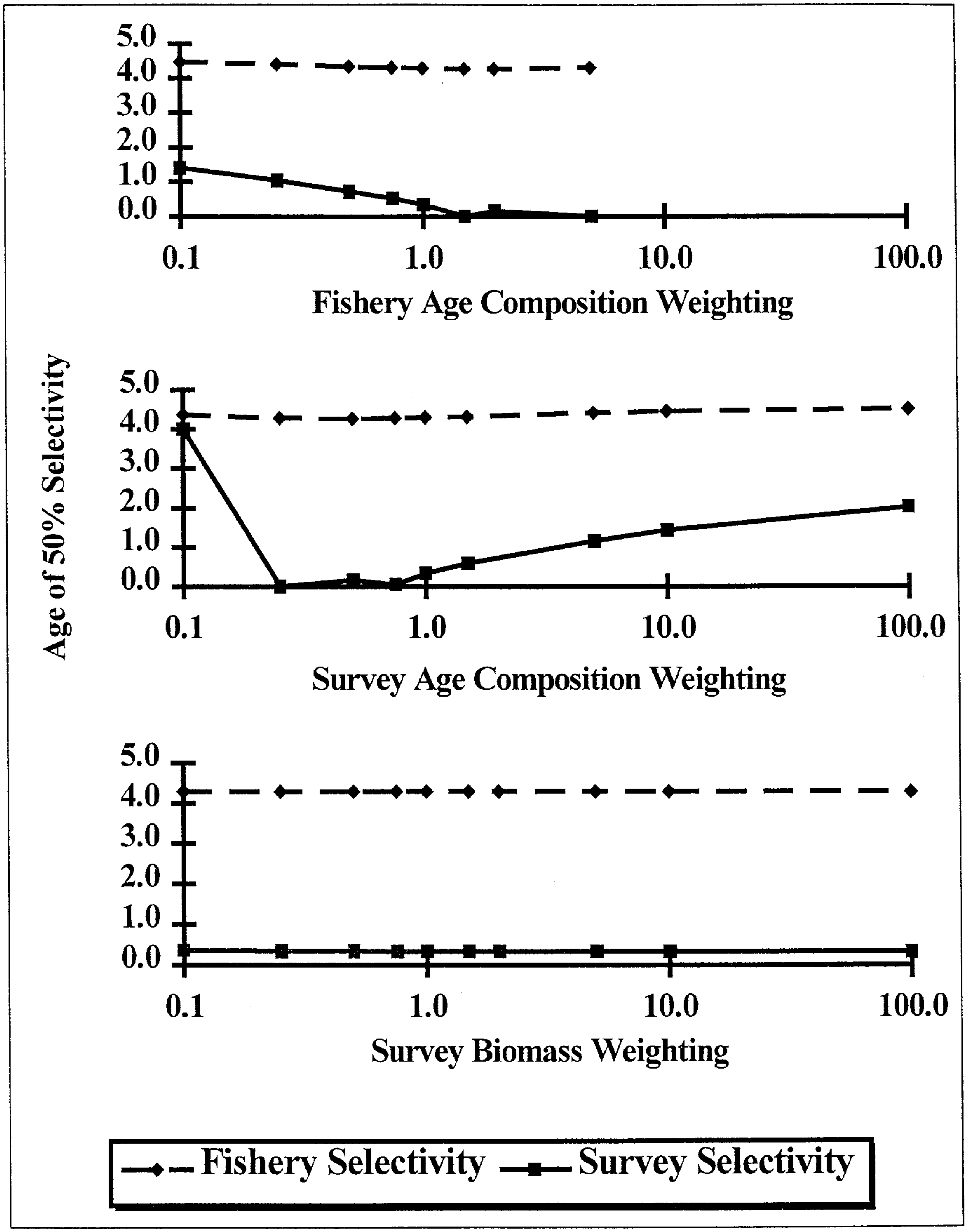

Figure 7. Changes in model estimates of the ages of 50% selectivity in the survey (dashed line) and the fishery (solid line) in response to source data weighting.

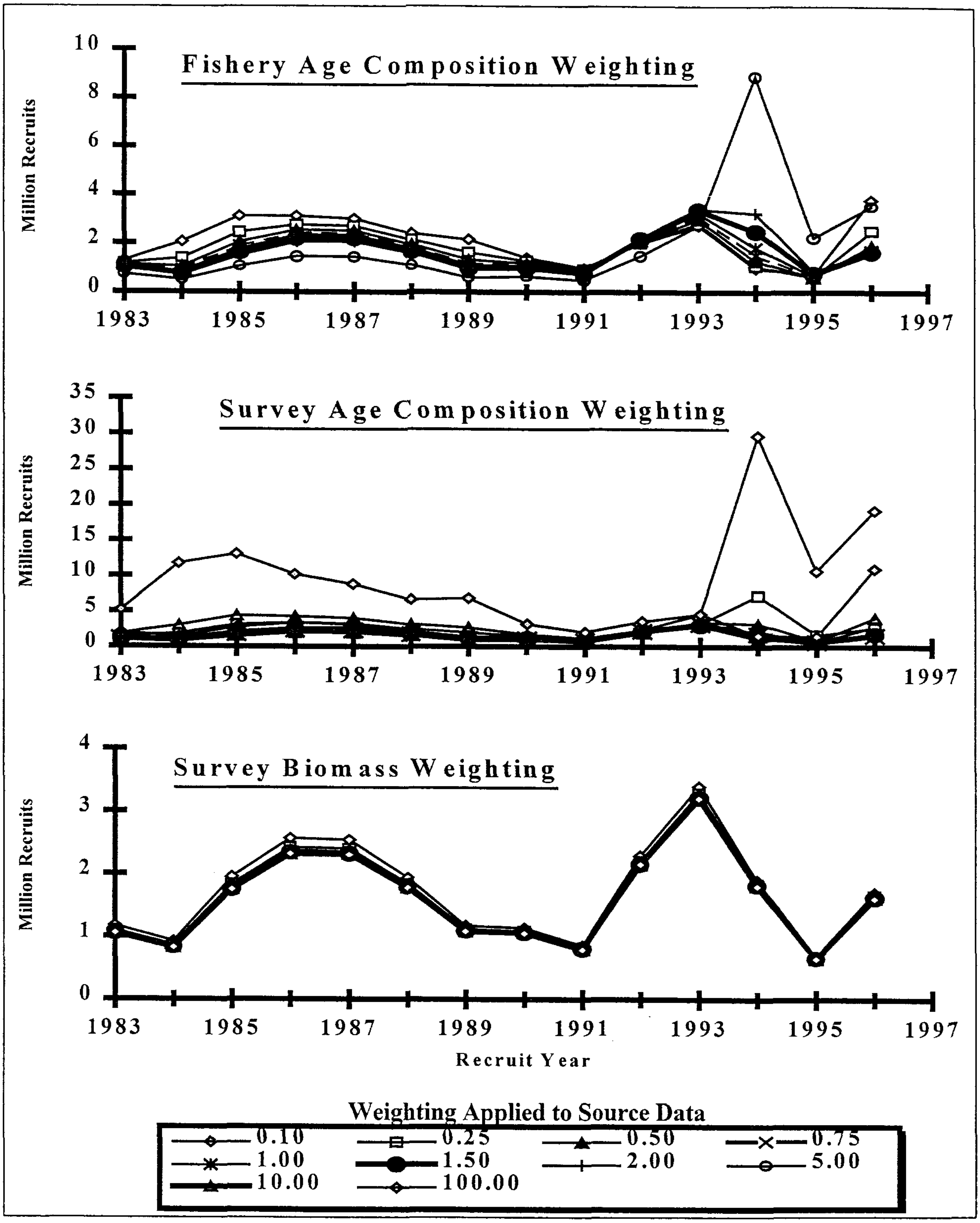

Figure 8. Effects of variable weighting of survey age composition, fishery age composition, and survey biomass data sets on model-estimated age-1 recruitment.

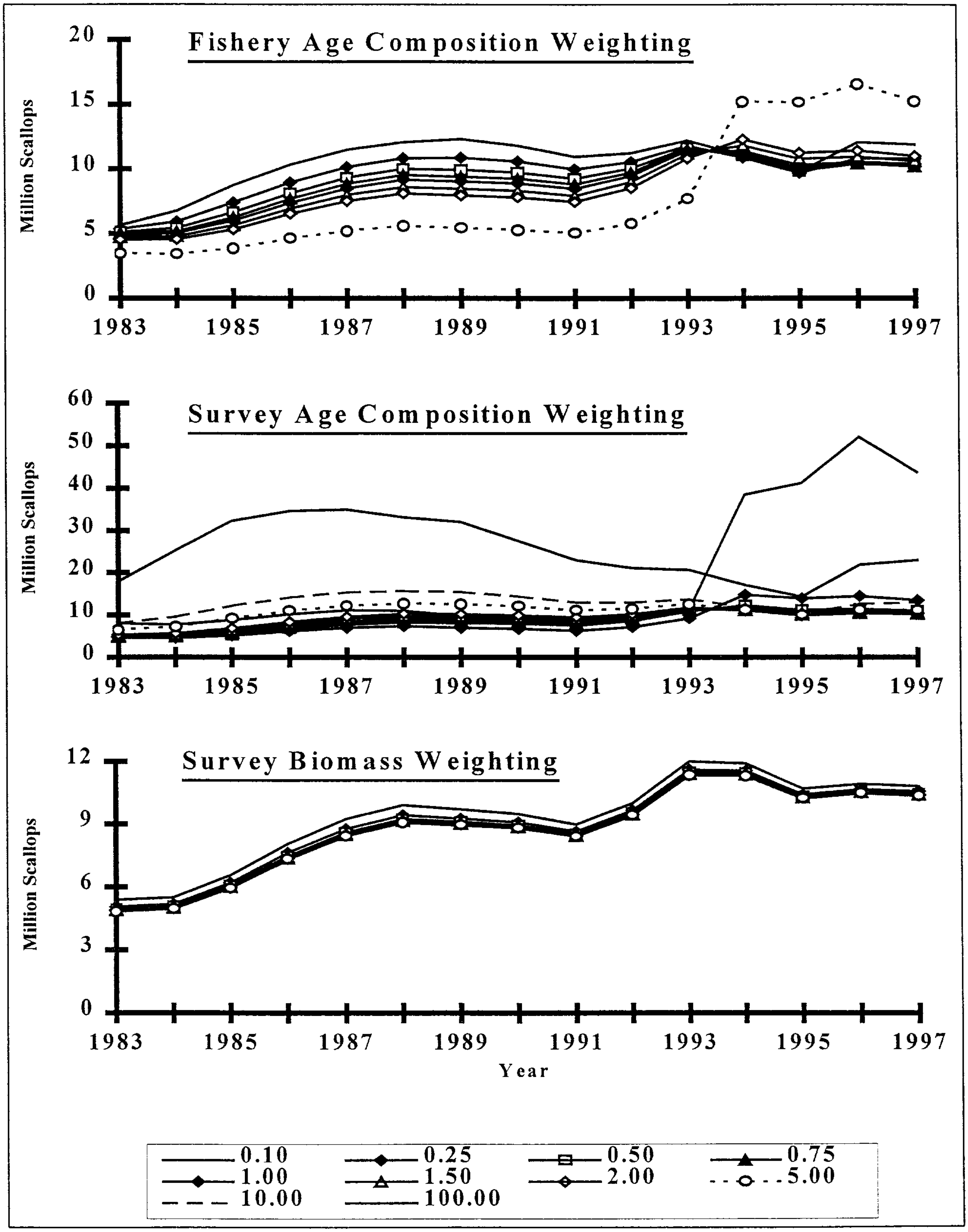

Figure 9. Effects of variable weighting of survey age composition, fishery age composition, and survey biomass data sets on age model-estimates of the population abundance.

Appendix A. Parameters and equations used in an age-structured model for weathervane scallops in Kamishak Bay, Alaska.

$\hat{N}_{a,y}$ = estimated number of age-a scallops in year y

$\hat{N}_{a+1,y+1} = S(\hat{N}_{a,y} - F_{a,y})$ = reduction equation

S = model-estimated, annual survival rate

$F_{a,y}$ = commercial fishery catch abundance of age-a cohorts in year y, calculated using the observed fishery age composition, the observed harvest biomass, and mean scallop weight-at-age

$$f_{a,y} = \frac{s_a \hat{N}_{a,y}}{\sum_{a=1}^{16} [s_a \hat{N}_{a,y}]} \text{ = expected fishery catch composition}$$

$$s_a = \frac{1}{1+e^{\beta(a-\alpha)}} \text{ = age-specific fishery selectivity function}$$

α = age at which fishery selectivity equals 50%

β = a steepness parameter

$C_{a,y}$ = observed survey catch composition

$$c_{a,y} = \frac{\rho_a \hat{N}_{a,y}}{\sum_{a=1}^{16} [\rho_a \hat{N}_{a,y}]} \text{ = expected survey catch composition}$$

$$\rho_a = \frac{1}{1+e^{\phi(a-\tau)}} \text{ = age-specific survey selectivity function}$$

τ = age at which survey selectivity equals 50%

ϕ = a steepness parameter

$$SSQ_{agecomp\_fshy} = \sum_y \sum_a \left(\sin^{-1}\sqrt{F_{a,y}} - \sin^{-1}\sqrt{f_{a,y}}\right)^2 \text{ = a measure of fishery composition fit}$$

$$SSQ_{agecomp\_svy} = \sum_y \sum_a \left(\sin^{-1}\sqrt{C_{a,y}} - \sin^{-1}\sqrt{c_{a,y}}\right)^2 \text{ = a measure of survey composition fit}$$

$$SSQ_{biom} = \sum_{y=1}^{2} \left[\ln\left(B_{y,svy}\right) - \ln\left(B_{y,mod}\right)\right]^2 \text{ = a measure of biomass estimates fit}$$

$B_{y,svy}$ = survey estimate of population biomass in year y

$B_{y,mod}$ = age model estimate of population biomass in year y

$$SSQ_{Total} = SSQ_{agecomp\_fshy}\lambda_{agecomp\_fshy} + SSQ_{agecomp\_svy}\lambda_{agecomp\_svy} + SSQ_{biom}\lambda_{biom}$$

= a measure of total goodness of fit after weighting model inputs

λ = weighting applied to model inputs

8.5% - meat recovery used to convert harvest biomass to live weight